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14. ABSTRACT

Our efforts to develop a manufacturable process for the fabrication of reliable SNS Josephson junctions have yielded very promising results. We have shown that devices may be tuned to operate at temperatures between 1K and the T_c of the undamaged superconducting materials by varying the length of the weak link and changing the amount of the ion damage. We have disseminated results on out high-T_c ion damage Josephson junctions in several publications listed at the end of this report.

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High T_c Superconductivity Physics and Devices

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I. In-plane SNS Junctions

Our efforts to develop a manufacturable process for the fabrication of reliable SNS Josephson junctions have yielded very promising results. The process utilizes high resolution e-beam lithography and ion damage. These are both processes that are commercial and can be easily scaled. Conduction occurs in the ab plane and is interface free. A schematic of the device concept is shown in Figure 1 and has been reproducably realized.

We have shown that devices may be tuned to operate at temperatures between 1K and the T_c of the undamaged superconducting material by varying the length of the weak link and changing the amount of the ion damage. We have examined the normal state and superconducting properties of these devices in two contexts, a de Gennes dirty limit proximity effect and a percolating path of superconducting filaments. We have found that a classical percolation effect model fits very well if we include the natural consequence of a temperature dependence of the "effective length" of the N region. Our understanding is at a level illustrated in Figure 2 where we show an I-V characteristic of a manufactured SNS junction (data points) with a model fit (solid line).

We have disseminated results on our high-T_c ion damage Josephson junctions in several publications listed at the end of this report.

An industrial study in collaboration with A.G. Sun of TRW, Inc. in Redondo Beach, CA has been completed. In that work, we fabricated 12 identical junctions on a single chip to assess the uniformity and reproducibility of the process. We then aged the samples for several months

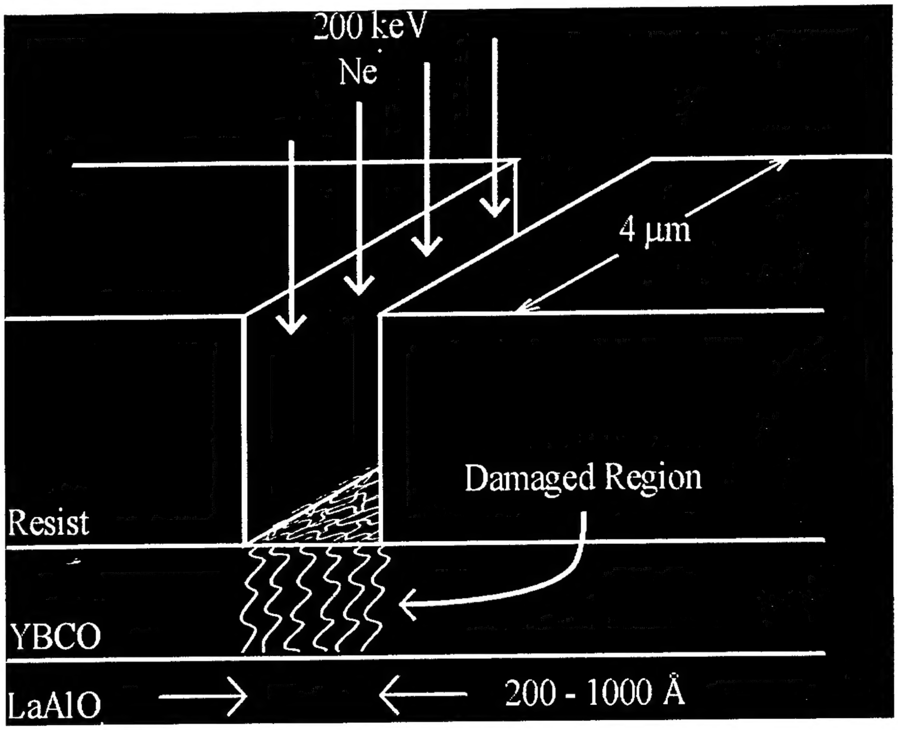
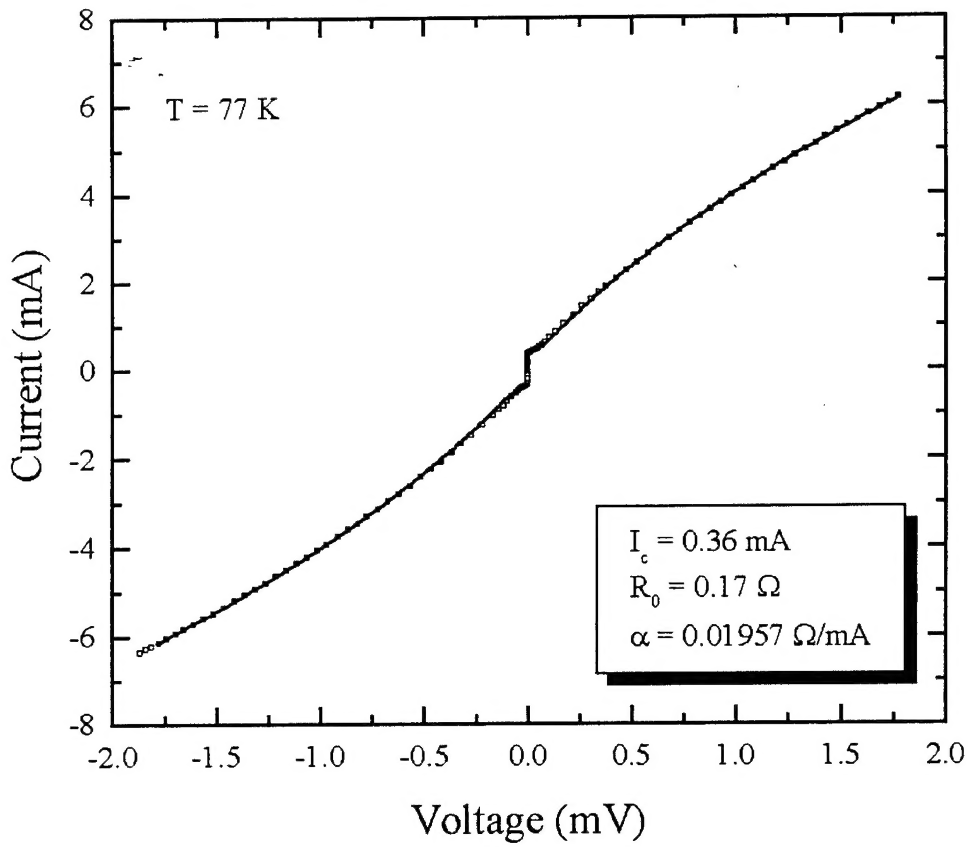


Figure 1. A Schematic of the device fabrication.

Figure 2. Fit to IV characteristic of an ion damage Josephson junction.



at room temperature and measured the same samples to assess the long-term stability of the process. In both cases, the junctions provided figures of merit that suggest ion damage junctions are a viable technology for a large-scale integrated circuit process. These results were presented at the 1998 Applied Superconductivity Conference.

Lifetime measurements have shown the devices are stable for over a year on the shelf. Since January 2000, Judy Wu (University of Kansas) has been in my lab as a visitor and we have also been in close collaboration with John Talvacchio (Northrup Grumman) to work on this optimization. The strategy to test the technology and hopefully transfer it for Air Force applications is to design test circuits compatible with Northrup Grumman test facilities, fabricate the circuits at UCSD using commercial processes, and after preliminary tests at UCSD, have them rigorously tested at Northrup Grumman. The processes have been refined at UCSD with a goal that the entire fabrication procedure can be ultimately performed in a foundary. We are aiming at our first test circuits to be sent to Northrup Grumman in the summer/fall of 2001. To take this from a research laboratory to a reproducible technology has required a substantial amount of rebuilding of equipment over the past year.

II. Electron Doped High T_c Superconductors $Nd_{2-x}Ce_xCuO_{4-d}$ (NCCO)

To study the universality of the effects of disorder on the high T_c superconductors, we have performed a study of electronic transport in ion-damaged thin films of the cuprate superconductor $Nd_{2-x}Ce_xCuO_{4-d}$ (NCCO). In this experiment, we measured the temperature dependence of the resistivity and the Hall coefficient of NCCO films irradiated with increasing doses of energetic helium or neon ions. From our results we could examine how this material is driven from superconductor to insulator with increased scattering and how the scattering rate and nominal carrier density evolves with increased damage.

NCCO is an exceptional cuprate in that it is electron-doped and it shows evidence for a near conventional gap in some experiments. Understanding how it is different from and similar to the other cuprates will help define the fundamental characteristics of perovskite superconductivity and the relative influence of crystal structure and electronic interactions on the properties of these materials. We found from our study (by examining the relation of T_c to residual resistivity) that the destruction of superconductivity in NCCO by damage is <u>very</u> similar to that of YBCO and other hole-doped cuprates. We explain this potentially surprising (based on electronic differences) result by proposing that the transition is driven by 2-dimensional disorder, i.e. that the transition is explained by the superconductor/insulator transition in 2-dimensional

films. All cuprates are composed of stacks of weakly coupled conducting Cu-O planes, so our explanation is natural and consistent with the data (the resistance per Cu-O layer at which T_c becomes zero agrees with the critical sheet resistance of the S-I transition in conventional 2 dimensional materials).

Our data also shows evidence for compensated conduction in NCCO. Increasing damage lowers the Hall coefficient at some temperatures and raises it at others, a result that can be explained by the existence of hole and electron carriers with different temperature dependent freeze-out. Past experiments by other groups have also implied that NCCO may be a compensated conductor. The highest damage films show an insulating/hopping temperature dependence at low temperatures with the same functional form as ion-damaged YBCO films in the insulating regime. A paper on this study was published in *Physical Review B*. The similarities between the effect of ion damage on NCCO and YBCO should make it possible to realize ion-damaged NCCO weak link junctions similar to the ion-damaged YBCO weak link junctions developed in our lab.

We also fabricated and measured NCCO/NCCO junctions across a bicrystal grain boundary. We laser ablate films of NCCO onto a 12°/12° YSZ bicrystal substrate, forming a natural junction. We have obtained both tunneling spectroscopy, showing a gaplike structure around zero bias of the correct energy for NCCO, and Josephson currents exhibiting Fraunhofer modulation in magnetic field. We studied the temperature dependence of both the spectroscopy and the Josephson tunneling and presented results of this study (along with earlier data from experiments on Pb/NCCO tunnel junctions) at the 1998 Applied Superconductivity Conference.

III. $Tl_2Ba_2CuO_{6+x}$ (Tl-2201) Optical Experiments

In collaboration with Dimitri Basov at UCSD, we have investigated the c-axis optical properties of the high-T_c superconductor Tl-2201 using IR reflectance spectroscopy. A set of measurements on optimally oxygen-doped crystals revealed, using a novel method of analysis, an anomalously large energy scale associated with the formation of superfluid condensate in this superconductor. In contrast to conventional superconductors, it appears that in Tl-2201 the superfluid borrows a significant portion of its spectral weight from energies above 6Δ (where Δ is the nominal superconducting gap). Analysis of earlier data on other cuprates shows that this effect appears generically in cuprates with incoherent c-axis response.

A further study of oxygen-overdoped Tl-2201 showed that the large energy scale observed in the optimally-doped crystals diminishes in size with increased doping. As

the material is overdoped and the c-axis response becomes more coherent, the behavior appears more conventional. Superfluid condensate is accumulated from a much smaller energy range on the order of the nominal superconducting gap. The results are consistent with a c-axis kinetic change in the cuprates at the superconducting transition, in contrast to conventional superconductors.

IV. Superconducting and Spin Dependent Tunneling in CoFe Thin Films

Superconducting tunneling and magnetoresistance has been demonstrated in junctions with native oxide bariers grown on $Co_{50}Fe_{50}$ thin films. When Pb is used as a counter electrode, the tunneling characteristics clearly reveal the presence of the Pb superconducting energy gap. A more detailed analysis of the tunneling characteristics show that the dominant conduction mechanism in these devices is tunneling and there is no measurable conduction by pinholes. This is an important observation as a substantial controversy continues as to whether such devices used for tunneling magnetoresistance applications are really tunnel devices or are a result of conduction through pinholes in the barrier. Junctions with Co counter electrodes rather than Pb show a maximum tunneling magnetoresistance of 2.5% at room temperature and 6% of 77K. These are the largest values reported to date in spin dependent tunnel junctions using a native oxide barrier. The oxide metal interface is clearly important as the junction performance depended strongly on the deposition conditions of the top ferromagnetic layer.

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Ph.D.s

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